

EMU EVOLUTION

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ABSTRACT

Evolution of Extravehicular Mobility Unit (EMU) technology is necessary to support the Extravehicular Activity (EVA) requirements of the Space Station Freedom Program and those of the Space Exploration Initiative (SEI). Key qualities supporting long-duration missions include technologies that are highly reliable, durable, minimize logistics requirements, and are in-flight maintainable and serviceable. While these qualities are common to SSF and SEI EVA, development paths will differ where specific mission requirements impose different constraints.

Development of reusable, regenerative technologies is necessary to minimize the logistics penalties. Increased battery discharge/recharge cycle life and useable wet life, compact high current density fuel cells, reusable CO₂ absorbing media, and thermal radiation coupled with venting heat rejection technologies are just some methods of reducing consumables. Development must strive for durable, reliable systems that are in-flight serviceable and maintainable, which are vital for missions where logistics capabilities are extremely constrained. Key areas include suit components (e.g. gloves, boots, and cooling garments), and life support hardware such as fans, pumps, instrumentation, and emergency O₂ systems.

Higher pressure suits will reduce EVA prebreathe requirements and pre-EVA operations overall. Many challenges of higher pressure suits have been addressed by on-going development. Emphasis on glove development is necessary to provide low fatigue, dexterous glove mobility at higher suit pressures.

Minimum impact hooks and scars which support an advanced SSF EMU have been identified. These accommodations permit upgrades that support servicing of low volume, high pressure oxygen systems, and hydrogen technologies such as fuel cell, and venting hydrogen heat rejection systems.

AGENDA

- Development Trends
 - History through STS EMU
 - Requirements vs Implementation
- SSF Baseline Requirements
 - Shuttle EMU enhancements to meet baseline
- SSF EVA Evolution Requirements & Implementation Paths
- SSF Evolution Hooks & Scars for Advanced EMU
- SEI EVA Concepts/Requirements
 - Common development paths (SSF & SEI)

DEVELOPMENT TRENDS

CATEGORY	REQUIREMENTS	IMPLEMENTATION
EVA Translation & Vehicle Proximity	EVA near vehicle (Gemini, Skylab)	Umbilical life support, venting
	No proximity restrictions (Apollo, Shuttle)	Independent, portable life support, closed-loop systems, compact packaging, increased complexity, maximum capacity for wt & vol
Equipment Service Life	Single Mission (Gemini, Skylab, Apollo)	Custom size suits, non-maintainable construction, limited life requirements ground maintenance & servicing
	Multiple Missions, long shelf life (Shuttle)	Standard sized suit components, maintainable modular construction, highly durable materials, more on-orbit servicing & maintenance
Crew Cabin Environment	3 - 5 psia (100% O2) (Gemini - Apollo)	Similar suit pressures, prebreathe completed prior to launch
	10.2 - 14.7 psia, O2, N2 mixture (Shuttle)	Increased: suit pressure, prebreathe protocol, suit & glove mobility

DEVELOPMENT TRENDS - TEXT

It is clear from the development of EVA capability in the U.S. Space Programs that the major shifts in the Extravehicular Mobility Unit (EMU) space suit and life support system design and implementation are driven by significant changes in the nature of the EVA mission and, to some extent, the nature of the specific program life and funding.

Early EVA missions of the Gemini program were conducted specifically to develop EVA requirements and techniques for future programs. As the character of EVA operations became better understood, the role of EVA shifted from that of 'flight experiment' to 'mission resource'. As EVA shifted to that of a mission resource, the EMU hardware life cycle shifted to fit not only the mission requirements, but the program life requirements as well.

The EVA missions of the Gemini, Skylab, and Trans-Earth Apollo required no extensive excursions far from the space vehicle. These systems tended to use open-loop, umbilically supported life support systems except when flight testing EVA equipment for different mission requirements. The Apollo-Lunar and the Shuttle program EVA mission requirements called for independent, portable life support systems. The Apollo-Lunar EVA requirements necessitated total independence from the vehicle in order to make EVA an effective resource for Lunar exploration and research. The Shuttle EVA missions, although generally conducted within the vehicle payload bay, are more broad in scope (such as satellite retrieval) and also require independent, portable life support. These systems had to be closed-loop, and tightly packaged to meet size, weight, and mobility requirements.

As program requirements shifted from single mission to continuing operations, the life cycle requirements and the construction of the EVA equipment shifted dramatically. The suits for Gemini through Apollo were custom made for each crewmember to optimize fit. The size and dynamic nature of the crew cadre for long-term programs such as Shuttle required smaller inventories of standard sized suit components and sizing elements to keep program costs low. Life support construction also shifted from low maintainable in-line construction to more maintainable modular construction to facilitate equipment processing with low inventory and enhance on-orbit maintenance and servicing.

SSF EMU BASELINE

- SSF program selected the STS EMU to reduce program cost
- STS EMU life support technologies

Primary Oxygen	900 psia compressed O ₂
Emergency Oxygen	6000 psia O ₂ , not rechargeable on-orbit
Heat Rejection	Water sublimation to space, venting
CO ₂ Control	Chemical absorption (LiOH), not regenerable
Humidity Control	Condensing heat exchanger with water separator
Power	Ag-Zn battery, 135 day wet life, 8 charge/discharge cycles

- Current certification

- 7 hour maximum EVA @ 1000 Btu/hr
- 30 minute emergency life support from high pressure O₂ system
- On-orbit rechargeable primary life support consumables
- Bends protection satisfied with 4.3 psia suit pressure and prebreath protocol
- 3 EVAs between ground checkouts

SSF EMU BASELINE - TEXT

The SSF program, as part of a program redefinition activity, selected the STS EMU as the baseline space suit and life support system to conduct SSF extravehicular activity. The decision was seen as a cost savings alternative to the program developing an advanced EMU specifically for SSF. The STS EMU system configuration, interfaces, and capabilities were designed specifically for Shuttle Orbiter interfaces, and Shuttle EVA mission criteria. Effort is underway to integrate the STS EMU into the baseline SSF EVA System.

The primary life support system provides 1.217 lbs of useful oxygen for metabolic consumption and other suit requirements. The primary oxygen is stored at 900 psia in the EMU portable life support system (PLSS) and is serviced from the Shuttle Orbiter Cryogenic Oxygen system. The STS EMU ventilation loop is closed. A non-regenerable contamination control cartridge is used to scrub carbon dioxide from the vent loop by chemical absorption. Humidity is removed with a condensing heat exchanger. A centrifugal water separator pumps the condensate to the EMU water tanks for later use in heat rejection. A pressure-regulated water-fed sublimator provides the major heat rejection and heat exchanger sink temperature for the STS EMU during EVA. Each EMU holds a minimum of 9.8 lbs of water for EVA heat rejection. An eight (8) charge/discharge cycle, silver-zinc battery provides the electrical power during EVA. The battery has a wet-life of 135 days after chemical activation.

The STS EMU can support a maximum EVA duration of 7 hours. If the average metabolic rate is at 1000 Btu/hr or less, the battery tends to be the limiting consumable. The nominal suit operating condition is at 4.3 psia with 100% oxygen concentration. Since the orbiter cabin condition is a mixture of oxygen and nitrogen at 10.2 psia to 14.7 psia, protection against decompression sickness is satisfied with an appropriate prebreathe protocol for the cabin condition. All of the EMU primary life support consumables are on-orbit serviceable. The EMU oxygen and water are serviced with ECLSS fluids via the EMU servicing subsystem. The batteries can either be charged in the EMU, or replaced with fresh batteries prior to the next EVA. The contaminant control cartridge is replaced prior to each EVA.

A 30 minute emergency open-loop life support capability is provided by a regulated 6000 psia oxygen package. This unit is not rechargeable on-orbit.

The STS EMU is currently certified for 3 EVAs per Shuttle mission between ground checkout cycles. Some limited life components currently constrain the maximum time between uses to 60 days.

SSF EMU BASELINE

- SSF EVA requirements exceed present STS EMU certification
 - 22 EVAs maximum between resupply periods assuming skip cycle
 - Consistent with requirement of 52 EVAs per year
 - Approximately 200 days between ground refurbishment
 - STS EMU enhancements underway to meet EVA demand and extended refurbishment interval
 - Recertification of current life support system and suit
 - Redesign and certification of some system filters
 - Increased maintenance interval on suit bearings and connectors
- Other STS EMU enhancements planned to streamline STS processing and on-orbit use
 - Captive fasteners on many life limited components
 - Improved suit resizing capability
 - Metal hard upper torso

SSF EMU BASELINE - TEXT

The SSF program baseline requirements call for the EVA System to support up to 52 EVAs per year at SSF permanent manned capability (PMC) phase. Three EMUs are on-board SSF at any given time (two prime units, and one backup). The EVA System and SSF must support up to 44 EMU recharges (equivalent to 22 two-man EVAs) between orbiter resupplies. This enables a moderate EVA capability should the SSF encounter a skip in the nominal orbiter resupply period as defined by the NASA Mission Operations Directorate.

<u>Period (Days)</u>	<u>SSF Operations Mode</u>	<u>EVAs per Period</u>
Nominal Resupply Skip Cycle	Nominal	13
	Nominal	6
	Contingency	3
		<hr/>
Totals		22
		<hr/>
90		
45 (first)		
45 (last)		
		<hr/>
180		

Assuming additional time for ground transportation and handling, the total time between EMU ground checkout could be 200 days. Also, the EMUs that are replaced will probably need to be able to support an orbiter contingency EVA raising the total requirement to 23 EVAs in 200 days. Since these requirements exceed current STS EMU capabilities, enhancements and testing are underway to extend the STS EMU in-flight service limits.

The majority of the STS EMU service life extension can be achieved by testing and recertification of current configuration space suit and life support hardware. This activity is in work. Some system filters require redesign and recertification to achieve desired service life goals.

Additional STS EMU design enhancements are planned to streamline processing of STS EMU equipment. Limited life system filters that significantly impact EMU performance will be identified by testing and those filters will be redesigned with increased capacity. Captive fasteners to speed replacement will be incorporated into this redesign. Suit sizing elements will be redesigned for rapid resizing of lower arms, and upper and lower leg suit segments. In addition, the space suit hard upper torso will be redesigned with aluminum to extend component service life.

SSF EVA EVOLUTION

- High EVA demand is forecast for SSF evolution scenarios
 - Impacts on logistics, crew time, EVA crew task data handling

■ Development Goals

GOAL	IMPLEMENTATION PATHS
Minimize logistics	<ul style="list-style-type: none">● Employ low venting, regenerative technologies● Maximize on-orbit service life of life support and space suit equipment● Employ low weight system configurations
Minimize crew time	<ul style="list-style-type: none">● Maximize equipment service life between maintenance intervals● Automate maintenance, servicing, and checkout functions● Electronic access of crew data● Decrease suit maintenance and resizing time
Minimize crew fatigue	<ul style="list-style-type: none">● Reduce/eliminate prebreathe time● Improve suit and glove mobility

SSF EVA EVOLUTION - TEXT

Both the Fisher - Price External Maintenance Task team and the Solutions team final reports forecast high EVA demand for maintenance on-board Space Station Freedom. In addition, SSF evolutionary scenarios, including vehicle processing for SEI, will dramatically increase EVA processing requirements. In order to effectively and efficiently meet these challenges, EVA impacts to logistics requirements, crew time, and EVA crew task data handling must be minimized.

The minimization of EVA related logistics penalties is critical to the success of any long duration space missions where on-board resources are at a premium. By developing and employing low venting and regenerable technologies to future space suit/EMU designs, precious on-board consumables are kept to a minimum. Other logistics penalties may be reduced by maximizing the on-orbit service life of both the life support and space suit equipment. By reducing equipment failure modes and extending system life, fewer on-orbit spares are required to maintain an EVA capability. Other systems concerns are reduced when low weight system configurations are employed, this not only reduced resupply weight but also reduces overall station weight as well.

Crew support prior, during and post EVA must be kept to a minimum to facilitate the efficient operation of other crew related activities. Crew time, as with all other limited on-board resources, must be optimized and used efficiently. By maximizing equipment service life between maintenance intervals and providing equipment with automated maintenance, servicing and checkout functions, crew maintenance task time can be significantly reduced. Another method of increasing EVA crew effectiveness is to provide electronic access to crew operations data. This would eliminate reliance on manually updated/printed cuff checklists, reduce data retrieval time, and enable access to the latest information and newly generated data that address unanticipated EVA problems. Suit maintenance and resizing is a time consuming event with today's EMU and new technologies and design principles must be employed to future designs to facilitate suit maintenance and resizing.

A significant problem with today's EMU is crew prebreathe requirements and suit and glove mobility both of which contribute to crew fatigue. By minimizing crew fatigue, more efficient and productive EVAs can be expected.

ADVANCED THERMAL CONTROL SYSTEMS

- NON-VENTING
 - VAPOR COMPRESSION RNTS
 - ICE PACKS
 - THERMAL ELECTRIC/WAX/RADIATOR (RNTS II)
 - METAL HYDRIDE HEAT PUMP (MHHHP)
- VENTING
 - VENTING METAL HYDRIDE HEAT PUMP (VMHHHP)
WITH AND WITHOUT RADIATOR
 - RADIATOR/VENTING LIQUID OXYGEN

Thermal - Text

Original SSF requirements allowed only a non-venting EMU system due to expendables resupply and equipment contamination issues. The following thermal control options were studied, and as shown, the non-venting requirement resulted in large, heavy systems:

<u>OPTION</u>	<u>VOLUME (ft³)</u>	<u>WEIGHT (lbm)</u>	<u>DURATION (hrs)</u>
ICE PACK	2.0	160	8 (6 @ 1000 + 2 @ 500 Btu/hr)
TE/WAX/RAD	1.7	138	8 (6 @ 1000 + 2 @ 500 Btu/hr)
MHHP	0.7	196	4 @ 1000

(The Vapor Compression RNTS was found to be infeasible at this time, due to the current state of the art in compressors.) In 1989, the no-vent requirement was relaxed to allow consideration of smaller, lighter thermal control options. Because of this new consideration, the goal has shifted to development of a system which not only minimizes weight and volume, but also minimizes consumables.

<u>OPTION</u>	<u>VOLUME (ft³)</u>	<u>WEIGHT (lbm)</u>	<u>DURATION (hrs)</u>	<u>LBM EXPENDABLES/EVA</u>
VMHHP	0.2	70	4 @ 1000	0.7
RAD/LOX	0.2	29	8 (6 + 2)	6.1

For easy comparison with the current state of technology, the following is a list of STS-EMU characteristics:

<u>OPTION</u>	<u>VOLUME (ft³)</u>	<u>WEIGHT (lbm)</u>	<u>DURATION (hrs)</u>	<u>LBM EXPENDABLES/EVA</u>
SUBLIMATOR & WATER TANK	0.49	26	7 @ 1000	8.9

ADVANCED VENT LOOP COMPONENTS

- CO₂ AND H₂O REMOVER
 - MOLECULAR SIEVES
 - TE CONDENSING HEAT EXCHANGER
 - DESICCANTS
 - SOLID AMINE (HCCS)
 - ELECTROCHEMICAL (ERCA)
- METAL OXIDE (MOCHR, MORES)
 - VENTING MEMBRANES
- PRIME MOVERS
 - AIR BEARING FAN

CO₂ AND H₂O - TEXT

The current STS-EMU utilizes non-regenerable Lithium Hydroxide (LiOH) for CO₂ removal and a sublimator cold plate condenser for humidity control. In order to minimize logistics and resupply costs, the currently envisioned CO₂ and H₂O removal technologies should be regenerable at reasonably low temperatures and power levels. Some of these systems are able to perform both vent loop functions. The table below shows a weight and volume comparison of the systems under consideration for an Advanced EMU life support system:

<u>OPTION</u>	<u>VOL_(in3)</u>	<u>WT_(lbm)</u>	<u>POWER_(W)</u>	<u>CO₂</u>	<u>H₂O</u>
TE CHX	100	8.0	20	NO	YES
DESICCANT	525	17.5	0	NO	YES
METAL OXIDE (MORES)	334	20.7	0	YES	NO
MOLE SIEVE	375	24.3	1	YES	YES
SOLID AMINE	2419	98.5	0	YES	YES
ELECTROCHEMICAL	1037	66.0	0.5	YES	YES
METAL OXIDE (MOCHR)	622	28.0	0	YES	YES
VENTING MEMBRANE	350	25.0	0	YES	YES

In addition to these CO₂ and H₂O removal components, development is underway for a low volume, and low power air bearing fan with variable speed control having potentially lower maintenance requirements than the current fan/pump/water separator assembly.

ADVANCED OXYGEN STORAGE AND SUPPLY

- HIGH PRESSURE OXYGEN
 - 3000-5000 psia
- SUBCRITICAL LIQUID OXYGEN
- SOLID OXYGEN
 - Metal Oxides

ADVANCED POWER SYSTEMS

- HIGH POWER DENSITY/CYCLE LIFE BATTERIES
- FUEL CELLS (FCESS)

O₂ and Power - Text

The current STS-EMU uses high pressure gaseous oxygen for suit pressurization and metabolic O₂ supply. The primary oxygen bottles have a pressure of 900 psia, while the Secondary Oxygen Pack (SOP) is at 6000 psia. The goal for advanced life support oxygen supply is to increase the storage density of the oxygen in order to decrease the weight and volume of the existing system. There are three ways in which to meet this goal.

The first way is to store the gaseous oxygen at very high pressures, i.e. 5000 psia. This will significantly decrease primary O₂ storage volume from 852 in³ to 527 in³. However, due to the increased pressure, the system weight is expected to increase from 12.6 lbm to 22.4 lbm due to thicker walls of the pressure vessel. This option has inherent problems as well as benefits, not the least of which is the concern for safety while operating at such high pressures.

A second way in which to increase the oxygen storage density is to use a liquid oxygen system. Liquid oxygen can be stored in roughly one-third the volume of an equivalent high pressure oxygen system, while greatly increasing the overall system safety. As a result of low pressure operation a comparable LOX system would be only 150 in³, and have an operating pressure of approximately 150 psia. The problems encountered with using a LOX storage and supply are due to the difficulty of working with liquids in a zero gravity environment, namely, system recharge and quantity gaging.

A third option for decreasing the oxygen system weight and volume is to store the oxygen in a solid form. An example of this solid storage would be regenerable metal oxide oxygen storage. System weight and volume for this candidate has not yet been determined.

Another area in which technology development is on-going is in power systems. Due the greater power requirements envisioned for an advanced EMU, and again the need to reduce logistics and resupply costs, more efficient power supplies must be created. More specifically, batteries must emerge which have a higher current storage density and a greater charge/discharge cycle life than those currently used on Shuttle missions. In addition to battery development, fuel cells must be investigated for their high energy storage levels and ease of recharge.

Each of the advanced system options discussed here have both a number of benefits, as well as associated problems. Each system must be studied and the advantages and disadvantages weighed before a final system choice can be made.

ADVANCED CONTROLS, INSTRUMENTATION, AND INFORMATION DISPLAYS

- HELMET MOUNTED DISPLAY (HMD)
- ELECTRONIC CUFF CHECKLIST (ECC)
- VOICE RECOGNITION SYSTEM (VRS)
- AUTOMATIC COOLING CONTROL (ACC)
- FAST RESPONSE CO₂ SENSOR (FRCS)

Displays and Controls - Text

The increased number of Extravehicular Activities (EVA) envisioned for the evolution of SS Freedom will dictate a need to increase crewman productivity and EVA efficiency overall. This increase can be accomplished through the faster dissemination of information to the EVA crew by means of an Electronic Cuff Checklist (ECC) or a Helmet Mounted Display (HMD). The ECC will allow for the storage of greater amounts of information than that currently available with the "paper" cuff checklist. Furthermore, the information display can be more easily accessed and updated than can the current system. Similarly, the HMD can allow a crewman access to even more information, which can be updated real-time from a ground- or space-based operation. Furthermore, when used in conjunction with a voice recognition system, the HMD can allow the crewman to access the needed information in a totally hands-free mode.

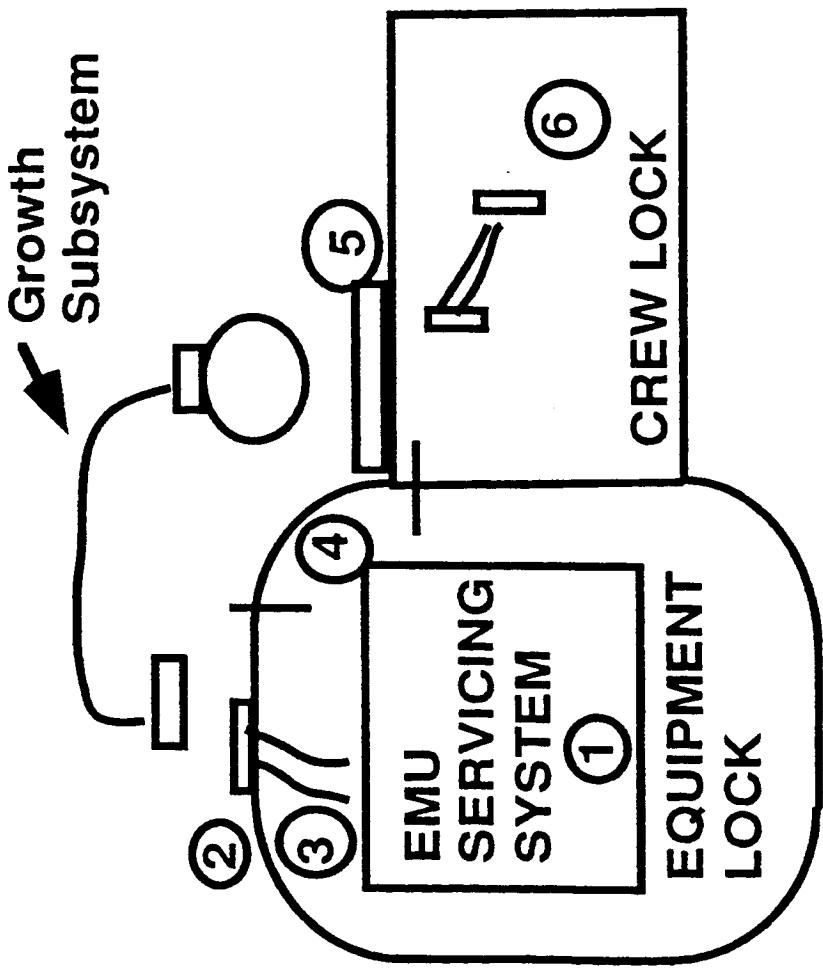
Another way in which to increase EVA efficiency is to incorporate an Automatic Cooling Control into the suit. This is a device which will sense the astronaut's metabolic activity level and operating environment and will adjust the amount of cooling through the Liquid Cooling Garment (LCG) accordingly. This automatic control has several benefits: 1) the crewmember does not need to interrupt important activities in order to adjust the cooling, 2) the crewmember is not distracted by the discomfort of becoming too hot or too cold, and 3) the thermal control system for the EMU will be smaller and lighter due to the more efficient use of the limited resources available.

In addition to these display and control methods, EVA productivity can also be increased through the use of more efficient EMU sensing systems. An example is the Fast Response CO₂ Sensor (FRCs). This system can sense a change in the CO₂ level of suit within seconds, and can be constantly updating the readings which allows CO₂ level to be used as another indication of metabolic rate. In addition, development of this new sensor has become a necessity for Space Shuttle because the current CO₂ sensor manufacturer is no longer making these sensors.

EVAS/AIRLOCK SCARS FOR ADVANCED EMU

Airlock has growth capability inherent in baseline design

- 1 Upgrade of EMU servicing system in EL at rack level
- 2 Few additional shell penetrations required
- 3 On-orbit plumbing additions possible
- 4 Growth capacity in shell and bulkhead power/avionics penetrations
- 5 Available mounting space for external growth subsystems
- 6 Upgrade of CL umbilical interface assembly



HOOKS AND SCARS FOR ADVANCED EMU - TEXT

The advanced EMU system configuration and technologies have many growth paths and the NASA has not selected any particular configuration. Sufficient hooks and scars should be incorporated into the baseline that complement inherent baseline growth capability to ensure that promising growth paths are not precluded.

Studies to date indicate that the airlock has growth capability inherent in the baseline design. Upgrade of the EVA System and airlock to support an advanced EMU can be accomplished with few additional hooks and scars. The most significant scar requirements accommodate external growth subsystems that service an advanced EMU with high pressure oxygen (3000 psia), and hydrogen. A high pressure oxygen compressor makes EMU primary and emergency O₂ on-orbit serviceable, and provides life support system packaging benefits. A hydrogen servicing subsystem would support promising advanced EMU technologies such as an EMU fuel cell and EMU cooling schemes that incorporate metal hydrides. A few additional airlock shell fluid penetrations are necessary to support the external growth subsystems. Existing power and avionics penetrations in the shell and bulkheads have adequate capacity to support growth scenarios. However, cabling must be added to the baseline to make full use of the growth capacity.

Upgrade of the EMU servicing system equipment located in the equipment lock (EL) can be done at the rack level. Preliminary evaluations show that rack weight and volume constraints can be met even with other distributed system equipment embedded in the racks. Rack level upgrade would require that other embedded equipment be duplicated in the growth racks.

Internal plumbing line additions to support new fluid services to the EMU servicing system can be made on-orbit for most fluids using a swage process that has been baselined for plumbing maintenance and repair. Leakage estimates for lines at 3000 psia using this swaging process range from 1x⁻⁵ to 1x⁻⁶ scc/s He. For installations of external subsystems, it is recommended that the utility scar design account for EVA access and operations with a pressurized glove. Judicious routing of utility lines and cables from shell penetrations to umbilical style interfaces will avoid EVA intensive on-orbit external plumbing and cabling.

Currently, mounting space that could be utilized by external growth equipment exists in the airlock baseline design. If the available space proved to be inadequate, scars to accommodate additional mounting grids would be a minor impact.

HOOK FOR COMMUNICATIONS WITH ADVANCED EMU

- NASA implementing digital UHF for dual use on SSF and STS
 - Allocations for current frequencies going away
 - Digital method more efficient use of frequency bandwidth
 - Time Division Multi-Access (TDMA) method selected
 - One frequency, multiple users (time slots)
 - Time slot allocations on-orbit selectable
 - This technique supports growth with proper hook
- Current implementation of digital UHF supports forward link audio communications with 4 EMUs
- SSF UHF operational modes resident in firmware
 - Mode 1: SSF-to-Orbiter
 - Mode 2: SSF-to-ACRV1 and ACRV2
 - Mode 3: SSF-to-4 EMUs, MSC, MTF
- Baseline operational modes preclude access by EVA astronauts to electronic data that support EVA operations
- Recommend hook that incorporates forward link data communications with advanced EMU
 - Mode n+1: SSF-to-4 EMUs including forward link(FL) data
 - Recommend further evaluation to define all growth modes
 - Less cost than hardware upgrade later in program

HOOKS AND SCARS FOR ADVANCED EMU - TEXT

Another growth capability that should not be overlooked with an advanced EMU is the ability to provide the EVA astronaut access to electronic data. This would include access to the latest EVA operations datafiles, as well as custom generated data that would address unforeseen EVA circumstances. Many of the EVAs to date were to fix problems, some of which required on-orbit mission planning. An ability to update or generate specific EVA operations data by ground and on-orbit personnel with subsequent transmission to EVA crewmembers will enhance the likelihood of mission success.

Currently, the EVA crewmember carries a printed cuff checklist. This method is not desirable for SSF operations because cuff checklists are not easily revised, require special materials and printing processes for vacuum compatibility, and would require crew time to replace cuff checklist pages.

NASA is implementing a digital ultra high frequency (UHF) communications system for dual use on SSF and the Shuttle orbiter for a variety of reasons including frequency allocation. A Time Division Multi-Access (TDMA) method was selected to implement the digital UHF communications. This method, with the proper hooks, supports growth scenarios. The TDMA approach time-shares many users (one user per time slot) on one frequency. Which users, and what data types (audio, or telemetry) are supported can be changed by selecting any one of a few pre-determined operational modes. Proper definition and baseline inclusion of the evolution operational modes will allow communication modes for evolution without further hardware changes.

The baseline digital UHF system includes modes that support 1) audio communications between SSF and STS Orbiter, 2) audio and data communications between SSF and the Assured Crew Return Vehicles (ACRVs), 3) audio communications with EMUs and data communications with the Mobile Service Center (MSC), and a Man-Tended Free Flyer (MTFF), etc. These mode configurations will be resident in firmware which is not on-orbit reconfigurable.

In order to support an evolution capability of providing EVA crewmembers access to electronic data, it is recommended that an additional operating mode be included in the baseline modes definition that supports audio communications and forward link data communications with the EMUs. This kind of change made in the baseline will be significantly cheaper than future on-orbit upgrades which require hardware changeouts.

SPACE EXPLORATION INITIATIVE

REQUIREMENTS	IMPLEMENTATION PATHS
EVA in Partial Gravity	Light weight system configurations, improved suit mobility for surface locomotion
EVA Translation & Vehicle Proximity	Independent, portable life support, closed-loop systems, compact packaging
Dust / Contamination	Environmental seals, suit cleaning, protective over-garments
Minimize Logistics	Employ low venting, regenerative technologies, Maximize on-orbit service life of life support and space suit equipment, Employ low weight system configurations
Crew Cabin Environment probably < 10.2 psia	Prebreathe with current suit pressures may be minimal or nonexistent
Equipment Service Life	Standard sized suit components, maintainable modular construction, highly durable materials, on-orbit servicing & maintenance compatible with mission requirements

SPACE EXPLORATION INITIATIVE-TEXT

EVA mission requirements for the Space Exploration Initiative (SEI) (i.e. Lunar base and manned Mars missions) will bring about additional changes in EMU technology development. While the development of an SSF EMU is the first step to the development of an SEI EMU, additional technologies are required for EVA in partial gravity and partial atmospheres.

EVA in partial gravity will require EMUs that are light weight and extremely mobile to enhance surface locomotion and to minimize crew fatigue. Surface exploration will place the crew member at a significant distance from main transportation vehicle requiring EMUs that maintain independent, portable life support, are closed-loop for maximum performance, and are compact and mobile.

Another problem arising from surface exploration is dust and contamination. EMUs will require environment seals to eliminate internal contamination. New suit cleaning procedures will have to be developed. A possible path to minimizing suit contamination is to develop a disposable EMU protective over-garment.

Due to the distance and duration of SEI missions, EMU logistics penalties must be kept at a minimum. One method of obtaining this goal is to employ low venting, regenerative technologies and to maximize on-orbit (or surface) service life of both life support and space suit equipment. In addition, all systems must be of low weight configurations to increase payload capabilities.

Prebreathe penalties with current suit pressures may be minimal or nonexistent, if the crew cabin pressures for SEI are maintained at 10.2 psia or below, which increases EVA readiness and minimizes some aspects of crew fatigue.

Equipment service requirements for SEI could be different for Lunar and Mars programs. Lunar EVA could be similar to the STS program where small inventories of equipment supports a dynamic EVA cadre and a high number of EVA sorties. Early Mars missions are more likely to be characterized by smaller EVA cadres, but extremely long mission durations. Design goals for these missions will strive to maximize equipment stay time at Lunar/Mars bases. These requirements call for EMUs that are of maintainable modular construction, are of standard sized/ rapidly resizeable suit components, are constructed of highly durable materials and have on-orbit servicing and maintenance compatible with mission requirements

COMMON SEI AND SSF EVA TECHNOLOGY PATHS

Life Support System	
Primary & Secondary Oxygen	<ul style="list-style-type: none"> ● High pressure storage ● Solid O₂ storage ● Subcritical L_OX
Heat Rejection	<ul style="list-style-type: none"> ● Radiator/Venting L_OX ● Radiator/Venting Metal Hydrides
CO ₂ & Humidity Control	<ul style="list-style-type: none"> ● Venting membranes (vacuum application) ● Light-weight, regenerable sorbents
Power	<ul style="list-style-type: none"> ● Long life, high cycle battery ● EMU Fuel Cell
Crew Data	<ul style="list-style-type: none"> ● Electronic Cuff Checklist ● HMD
Instrumentation	<ul style="list-style-type: none"> ● Fast response, long-life, self-correcting sensors for CO₂, O₂, humidity, flow, and contamination
Space Suit	
Mobility	<ul style="list-style-type: none"> ● Improved glove mobility at any pressure ● Reduced torque elbows and knees
Suit Sizing	<ul style="list-style-type: none"> ● In-situ, rapid suit resizing

COMMON SEI AND SSF EVA TECHNOLOGY PATHS - TEXT

Common implementation paths were indicated in some areas to meet both SSF and SEI requirements. Common implementation point to common technology paths when compatible with other constraints specific to either SSF or SEI missions.

The common technology paths indicated for the portable life support system areas of primary & secondary oxygen, heat rejection, CO₂ & humidity control, and power support the often conflicting goals of reducing logistics penalties, and providing a fully serviceable light-weight, low-volume EMU. The oxygen technologies are compact with the subcritical LO_x being the lightest technology approach. The heat rejection can be accomplished with radiators coupled with venting technologies for supplemental cooling. Venting membranes for CO₂ and humidity control also reduce system heat rejection penalties often associated with closed-loop methods of heat rejection. If logistics constraints demand closed-loop solutions, light-weight regenerable sorbents must be developed to minimize system weight. Long life, high charge/discharge cycle batteries and fuel cell technology will both reduce the logistics penalties for EVA.

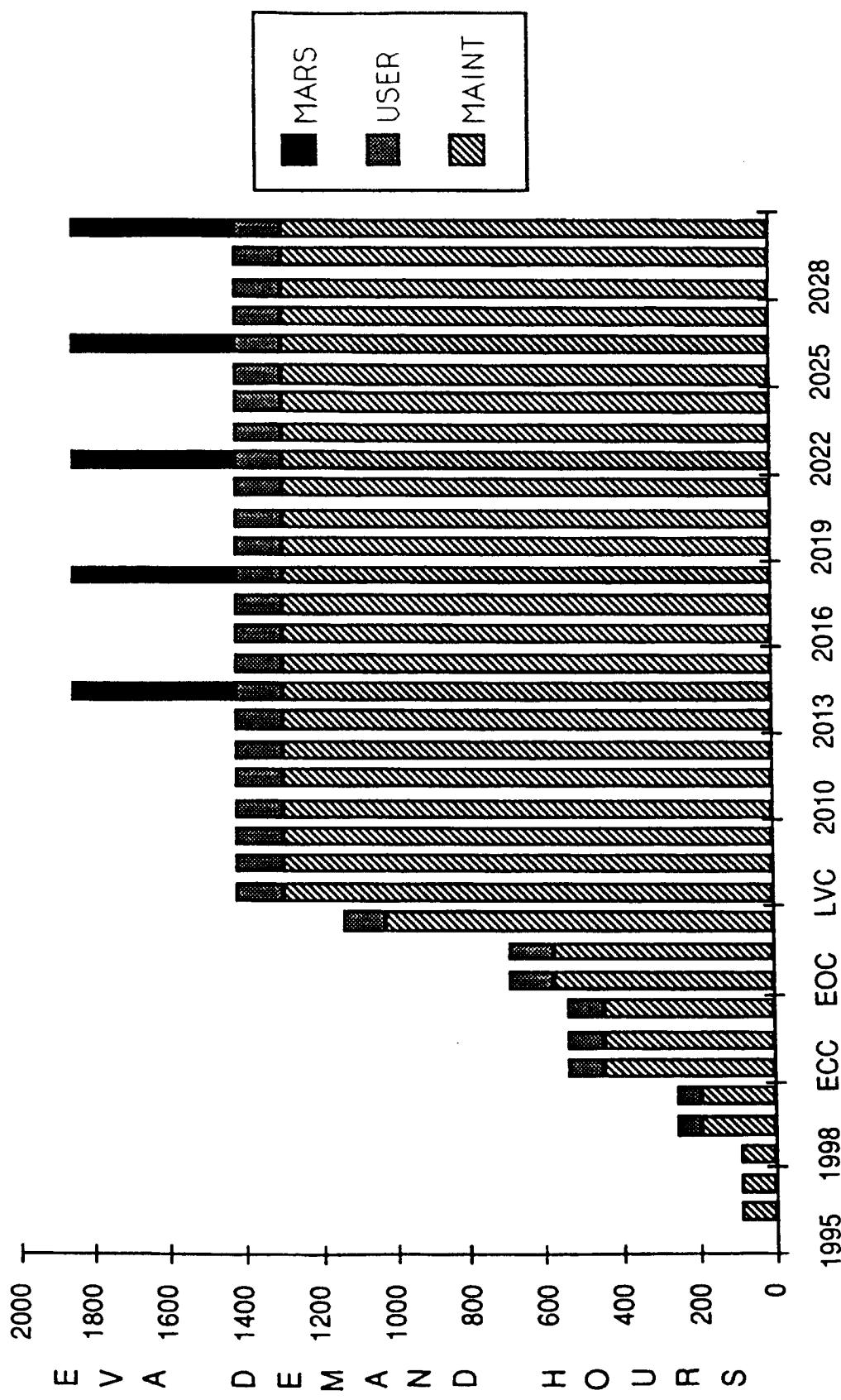
Technology paths such as an electronic cuff checklist, and helmet mounted displays, that support access and display of crew data, will enhance overall EVA operations while increasing the likelihood of mission success.

Highly reliable, self-correcting or calibrating instruments are critical to minimizing logistics penalties and crew time associated with life support system maintenance. Oxygen pressure sensors are often embedded in high pressure or LO_x systems. Embedded sensors can drive the refurbishment cycle of larger subsystems. Fast response sensors enhance overall system caution and warning response to system malfunctions, as well as, provide data that supports automatic system control.

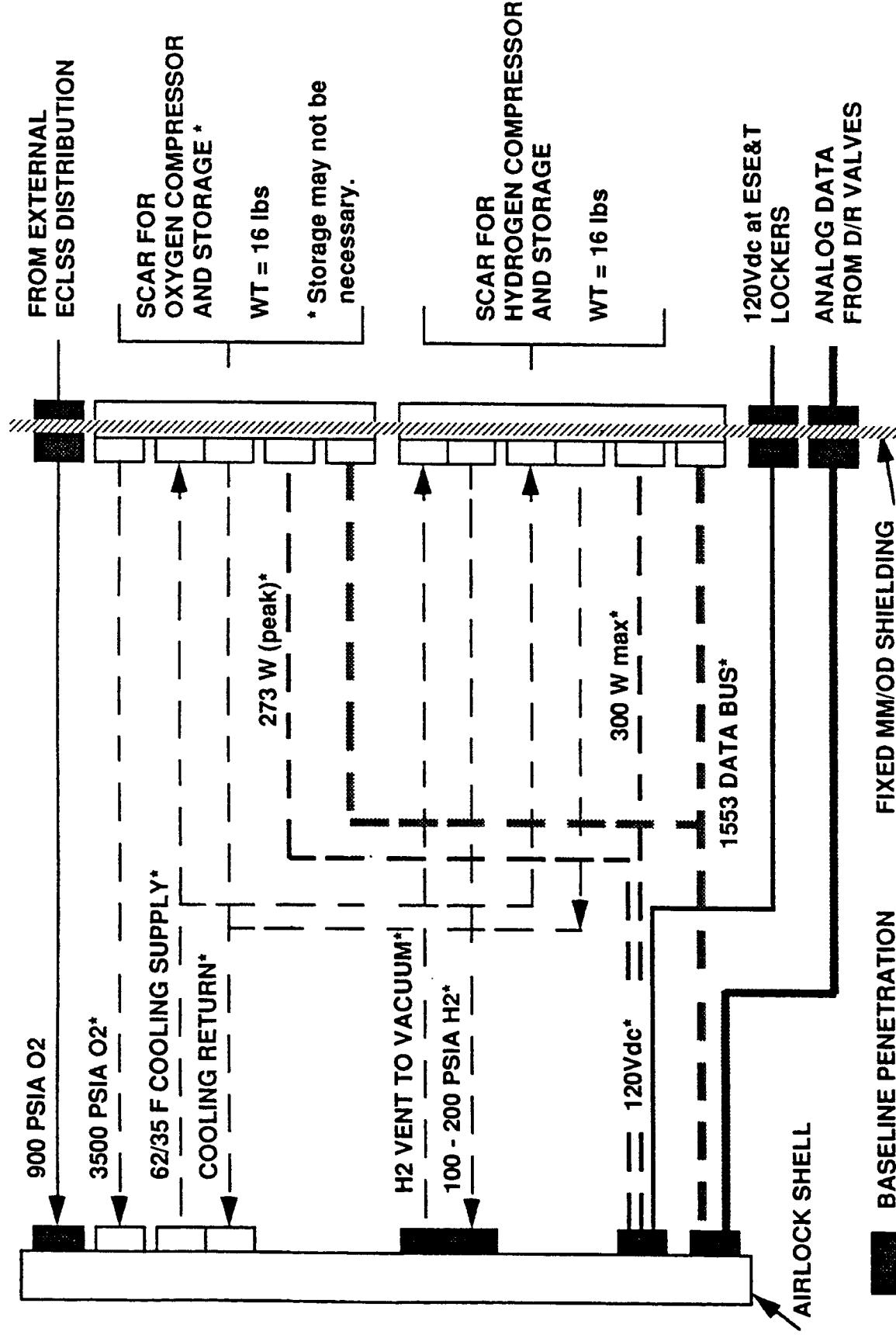
Common suit development paths for SSF and SEI will continue to increase suit and glove mobility to enhance EVA crewmember effectiveness. In-situ, rapid suit resizing capability will also reduce logistics and crew time penalties associated with the resupply of EVA crew and equipment.

BACKUP CHARTS

POTENTIAL EVOLUTION SSF EVA DEMAND



EXTERNAL AIRLOCK SCARS FOR ADVANCED EMU - FUNCTIONAL DIAGRAM



* GROWTH FUNCTION DESCRIPTION

■ BASELINE PENETRATION

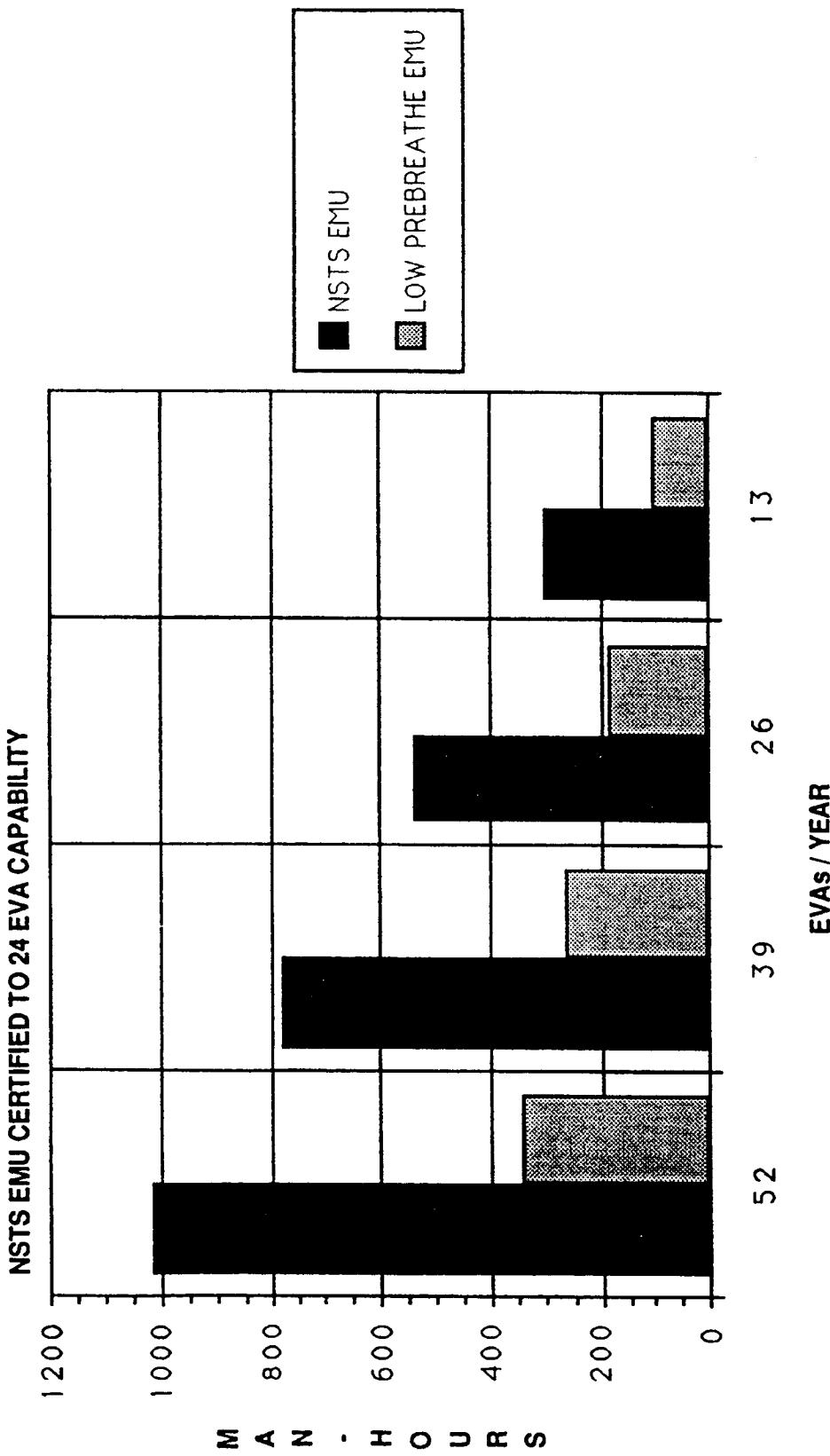
□ SCAR PENETRATION

— SCAR UTILITY DISTRIBUTION

INTERNAL AIRLOCK INTERFACES FOR ADVANCED EMU

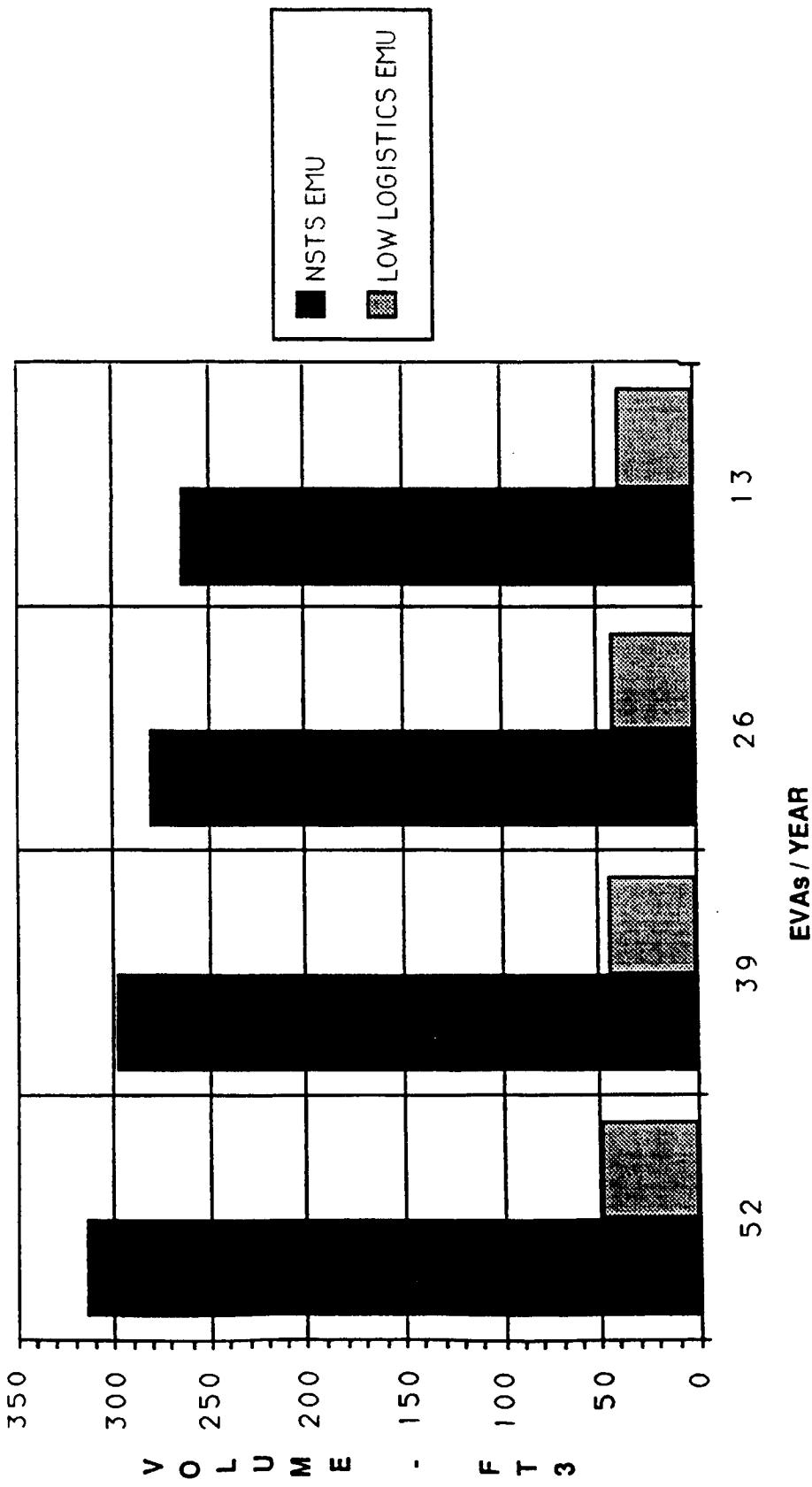
- On-orbit plumbing upgrades to support advanced EMU servicing system possible using swage process baselined for fluid line maintenance and repair
 - 3500 psia O2
 - Internal Temperature Control System lines for external subsystems
 - 100 - 200 psia H2
- Existing Equipment Lock (EL) to Crew Lock (CL) penetrations support advanced EMU except digital data communications with servicing system
 - Spare pins in existing avionics penetrations to CL able to support growth for digital data communications
 - Adequate cabling/pigtails from spare pins required to support growth
- On-orbit upgrade of advanced EMU servicing system equipment in the EL is possible at the rack level
 - Upgrade volume and weight estimates consistent with baseline constraints
 - Assumes worst case impacts to servicing system
- On-orbit upgrade of CL umbilical equipment also required

ANNUAL IV CREW TIME REQUIREMENT COMPARISON



ANNUAL LAUNCH VOLUME COMPARISON

NSTS EMU CERTIFIED TO 24 EVA CAPABILITY



ANNUAL LAUNCH MASS COMPARISON

